

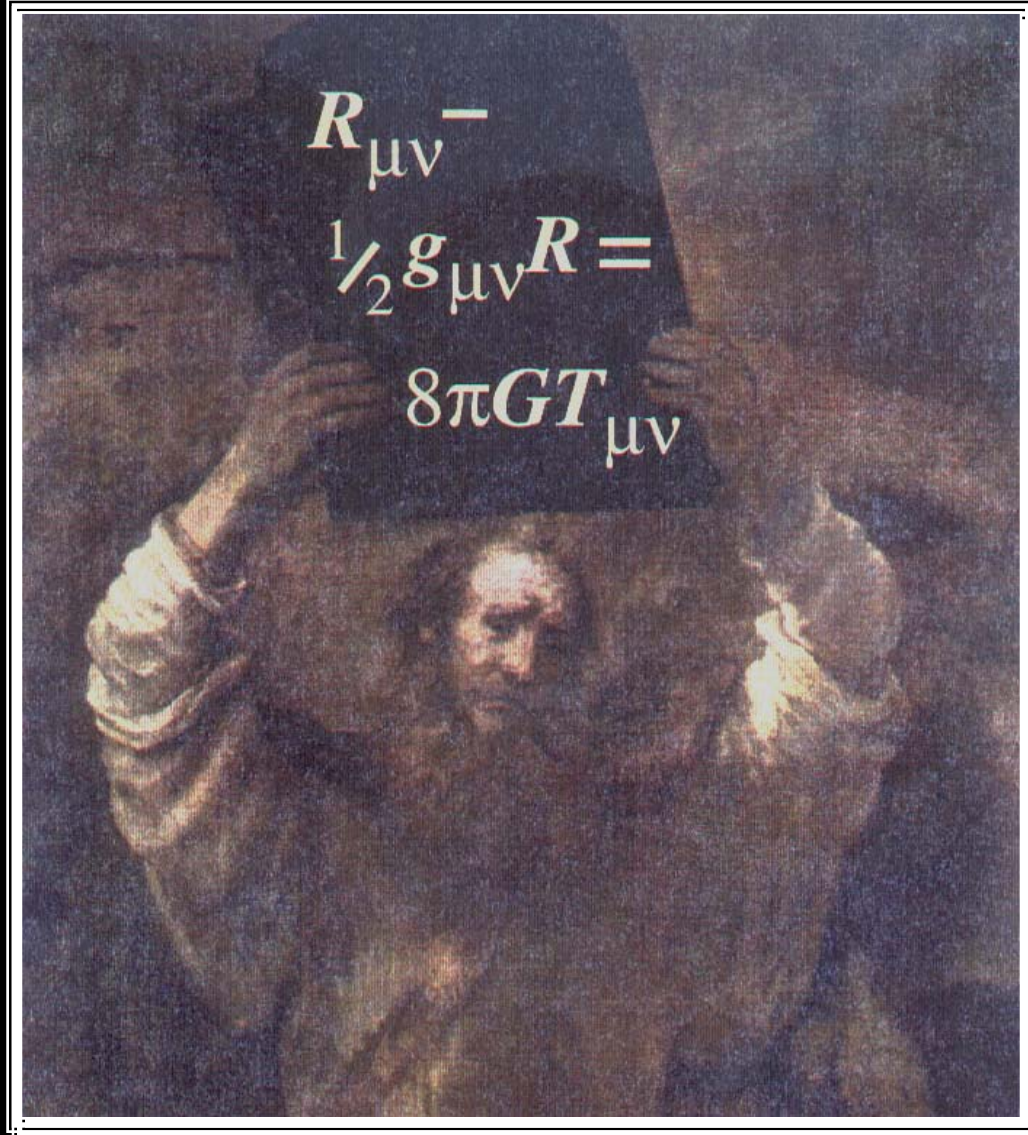
A large billboard is shown against a blue sky with white clouds. The billboard has a white background with black text. The text reads: "Big Bang Theory, You've Got To Be Kidding. -God". The billboard is mounted on a dark metal structure. The text is in a serif font, with "Big Bang Theory," in a larger size than the rest. The signature "-God" is in a cursive script.

**Big Bang Theory,**  
You've Got To Be Kidding.  
-God

# **News of the week**

- No office hours today
- Lab this week: 2<sup>nd</sup> week of geometry of the universe
- Lab next week: The Hubble constant
- Exam #2: May 20<sup>th</sup>
- Last lecture: Tuesday June 1<sup>st</sup>
- Final Exam: Tuesday, June 8<sup>th</sup>, 10:30am-12:30pm

# ***Modern laws of Genesis***



(10 nonlinear partial differential equations)



**"When the Special Theory of Relativity began to germinate in me, I was visited by all sorts of nervous conflicts... I used to go away for weeks in a state of confusion."**

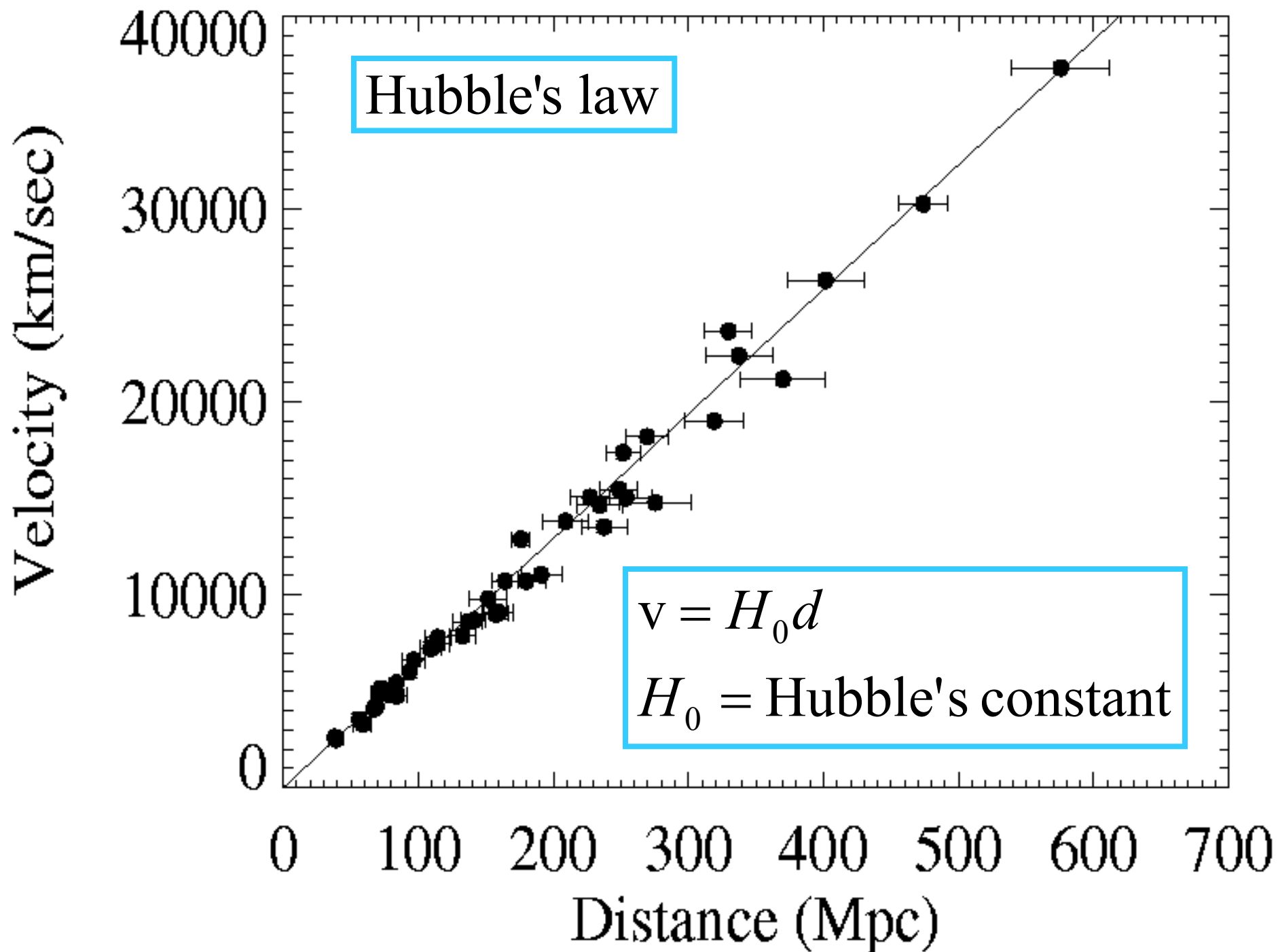
**"A storm broke loose in my mind."**

**Einstein, ca. 1905**

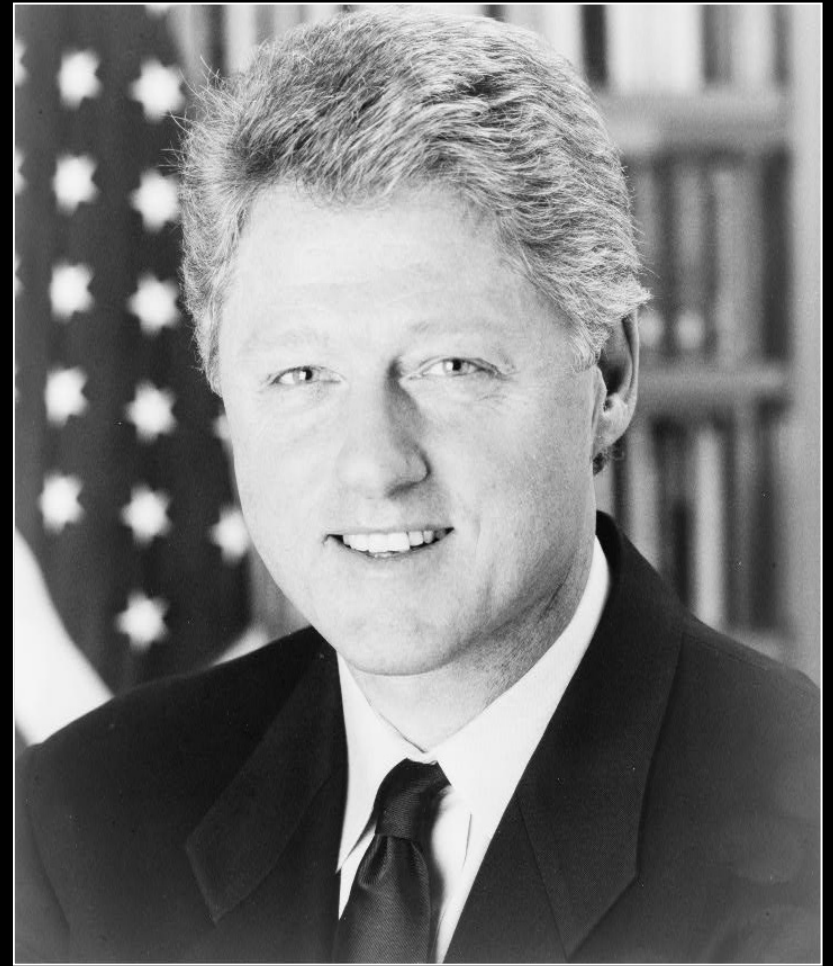
# **Albert Einstein 1879-1955**



**I see in Nature a magnificent structure... that must fill a thinking person with a feeling of humility..."**



# **Two famous Rhodes Scholars:**



**Politics is for the moment; an equation is forever.**  
***A. Einstein***

# *Famous and not so famous :*



Jessica Simpson



Michael Jackson



John Bardeen

**The  
red  
shift**

$$\frac{\lambda - \lambda_0}{\lambda_0} = z$$

$\lambda$  **detected wavelength**

$\lambda_0$  **emitted wavelength**

$z$  **redshift**

$v$  **recessional velocity**

$c$  **velocity of light**

$$c = 3 \times 10^5 \text{ km s}^{-1}$$

If  $v/c < 1$ ,  
then  $z = v/c$

Hubble's law:

$$v = H_0 d \rightarrow cz = H_0 d$$

**We are not the center of the expansion of the universe**

**Every galaxy sees the expansion**

# **Cosmological Principle**

**The universe is the same everywhere**

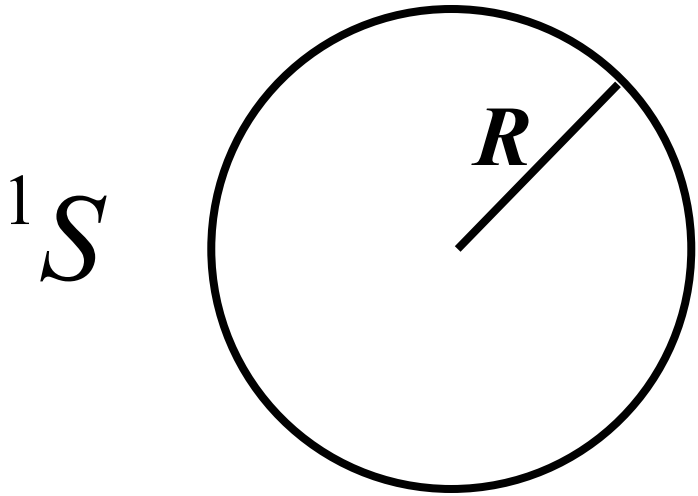
- **no special point in the universe  
(no center)**
- **no special set of points  
(no edge)**

# Spaces that obey the cosmological principle:

## 1-dimension:



$$V = \int_{-\infty}^{\infty} dx = \infty$$

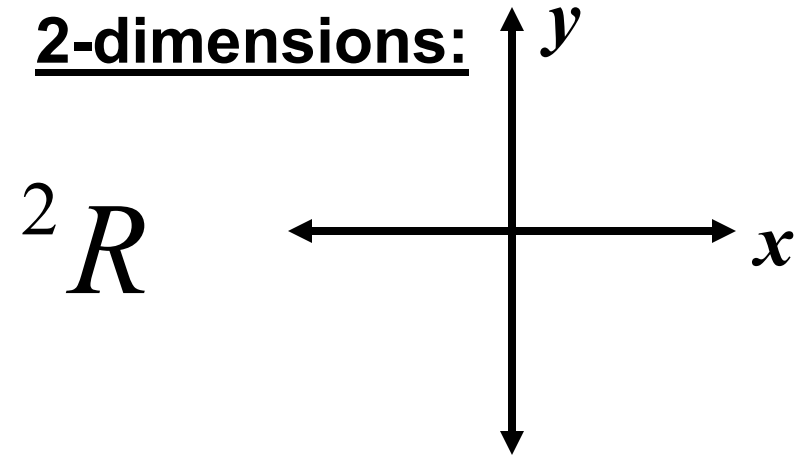


$$x^2 + y^2 = R^2$$

$$V = R \int_0^{2\pi} d\phi = 2\pi R$$

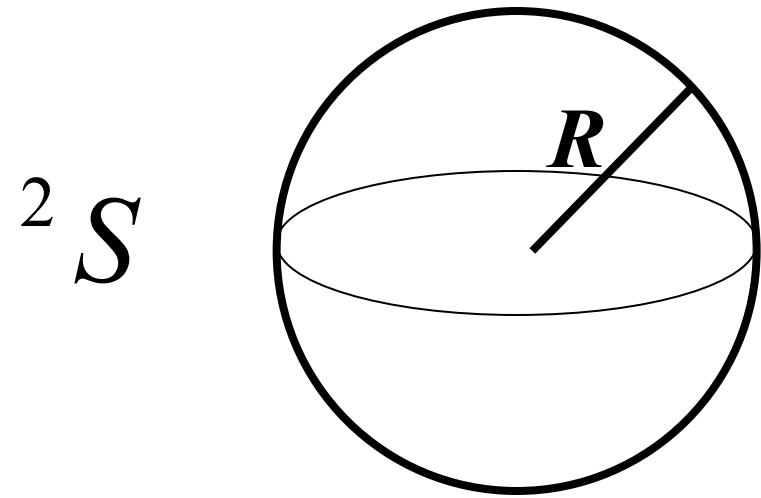
# Spaces that obey the cosmological principle:

2-dimensions:



${}^2R$

$$V = \int_{-\infty}^{\infty} dx \int_{-\infty}^{\infty} dy = \infty$$



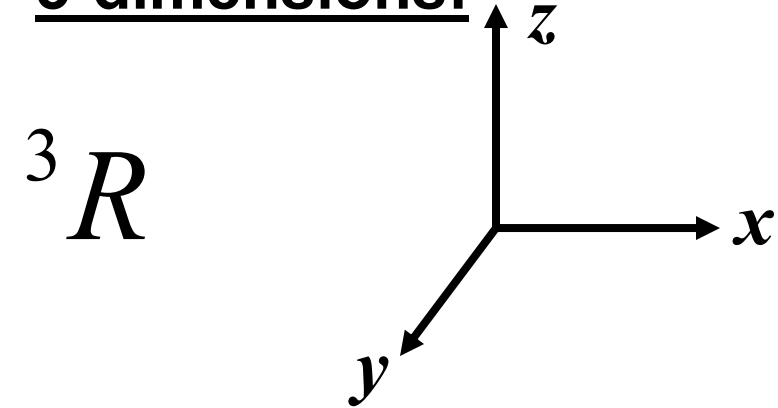
${}^2S$

$$V = R^2 \int_0^{\pi} \sin \theta \, d\theta \int_0^{2\pi} d\phi = 4\pi R^2$$

$$x^2 + y^2 + z^2 = R^2$$

# Spaces that obey the cosmological principle:

3-dimensions:



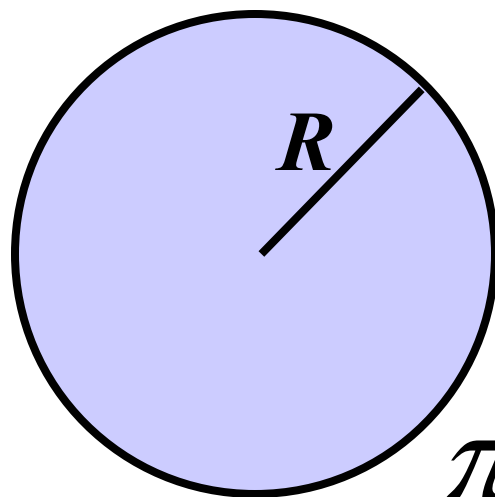
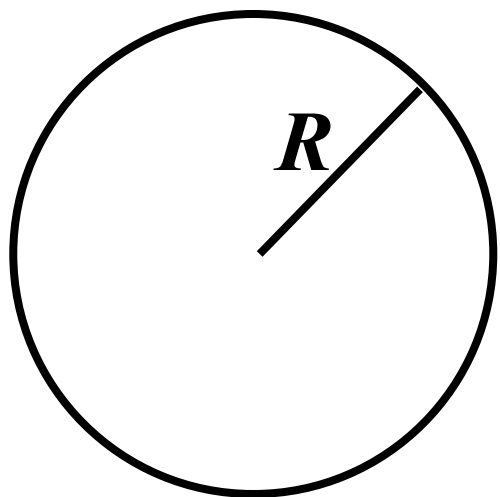
$$V = \int_{-\infty}^{\infty} dx \int_{-\infty}^{\infty} dy \int_{-\infty}^{\infty} dz = \infty$$

${}^3S$

$$V = R^3 \int_0^{\pi} \sin^2 \chi \, d\chi \int_0^{\pi} \sin \theta \, d\theta \int_0^{2\pi} d\phi = 2\pi^2 R^3$$

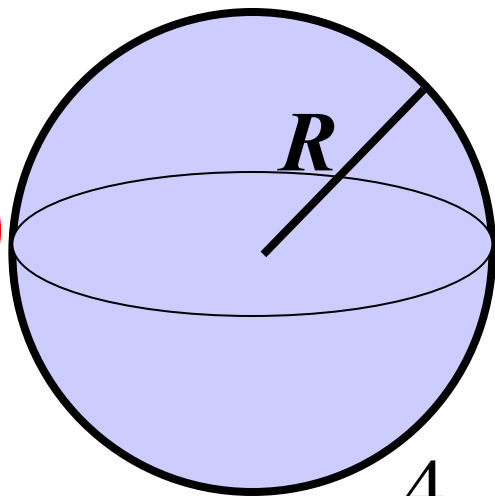
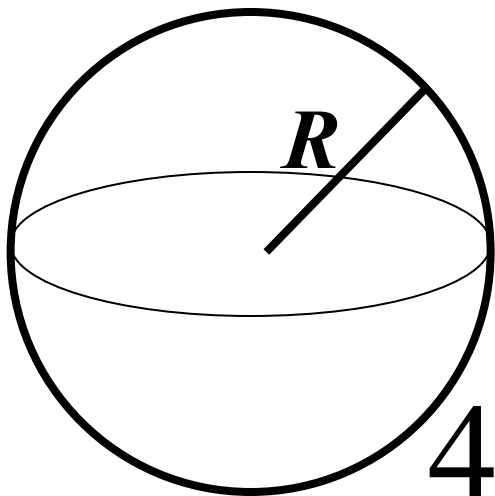
$$x^2 + y^2 + z^2 + w^2 = R^2$$

$^1S$



$$\pi R^2$$

$^2S$



$$4\pi R^2$$

$$\frac{4}{3}\pi R^3$$

$^3R$

$^3S$

$^3H$



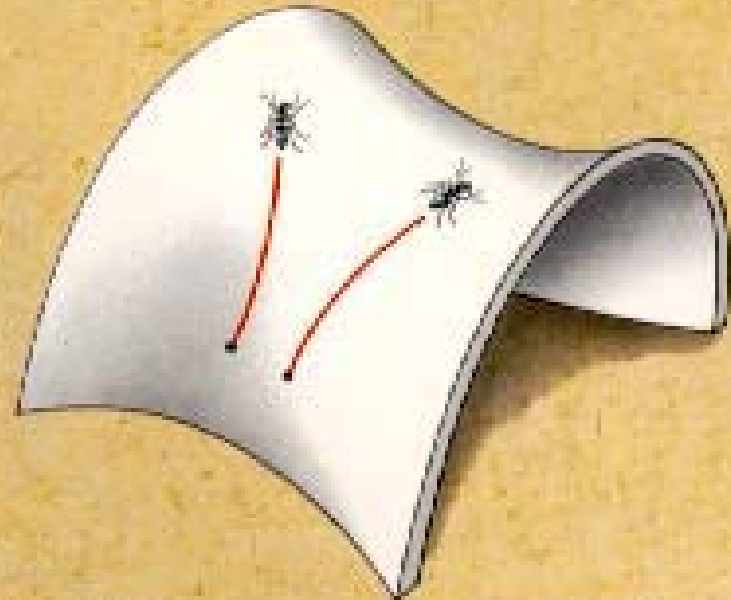
ZERO CURVATURE

FLAT



POSITIVE CURVATURE

SPHERICAL



NEGATIVE CURVATURE

HYPERBOLIC

**The expansion of the universe is**

**an explosion of space**

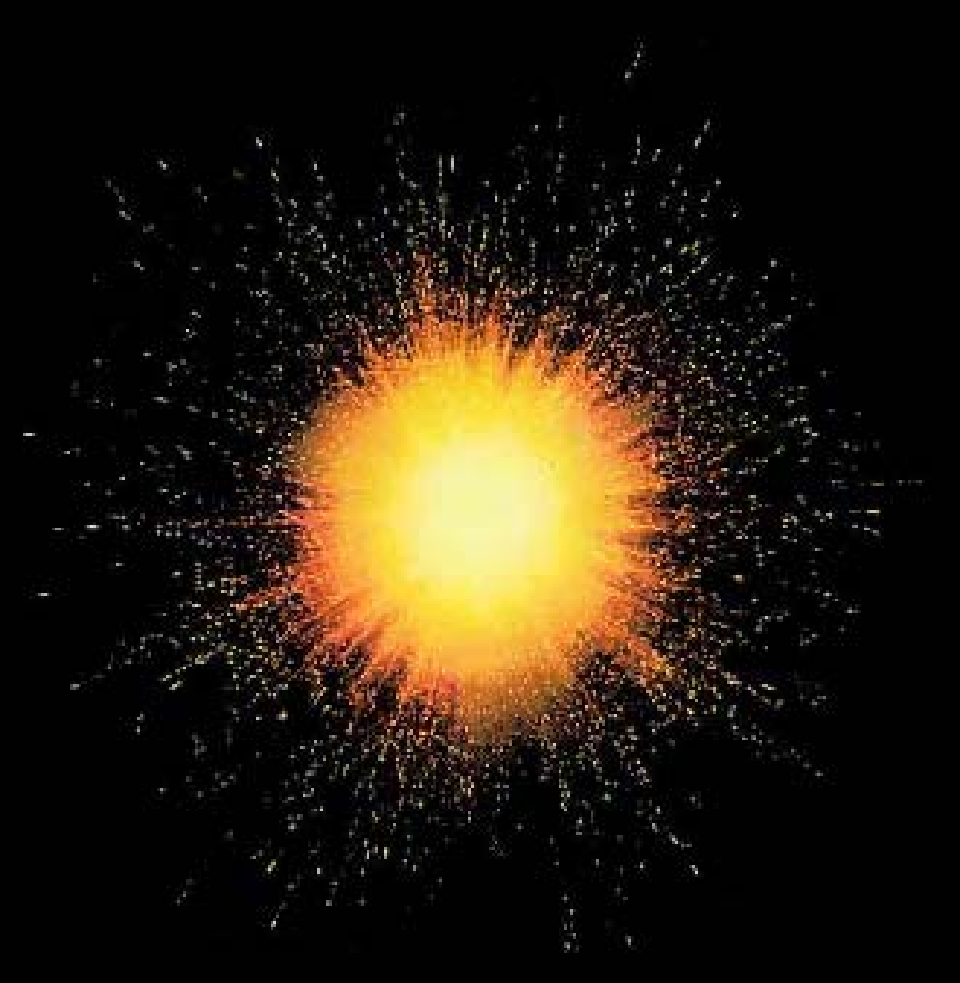
**not**

**an explosion into space**

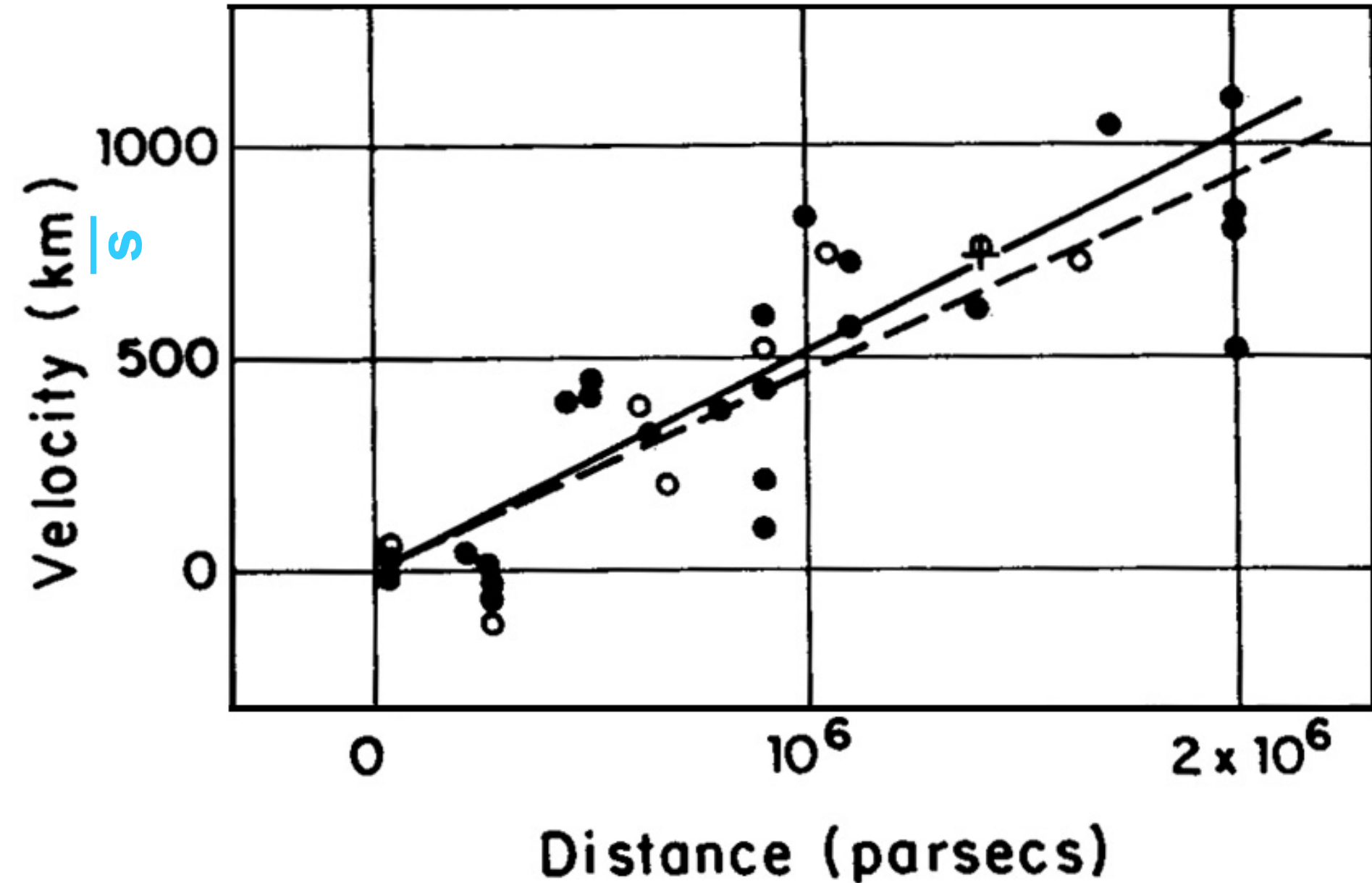
***This is not the big bang!***



***This is not the big bang!***



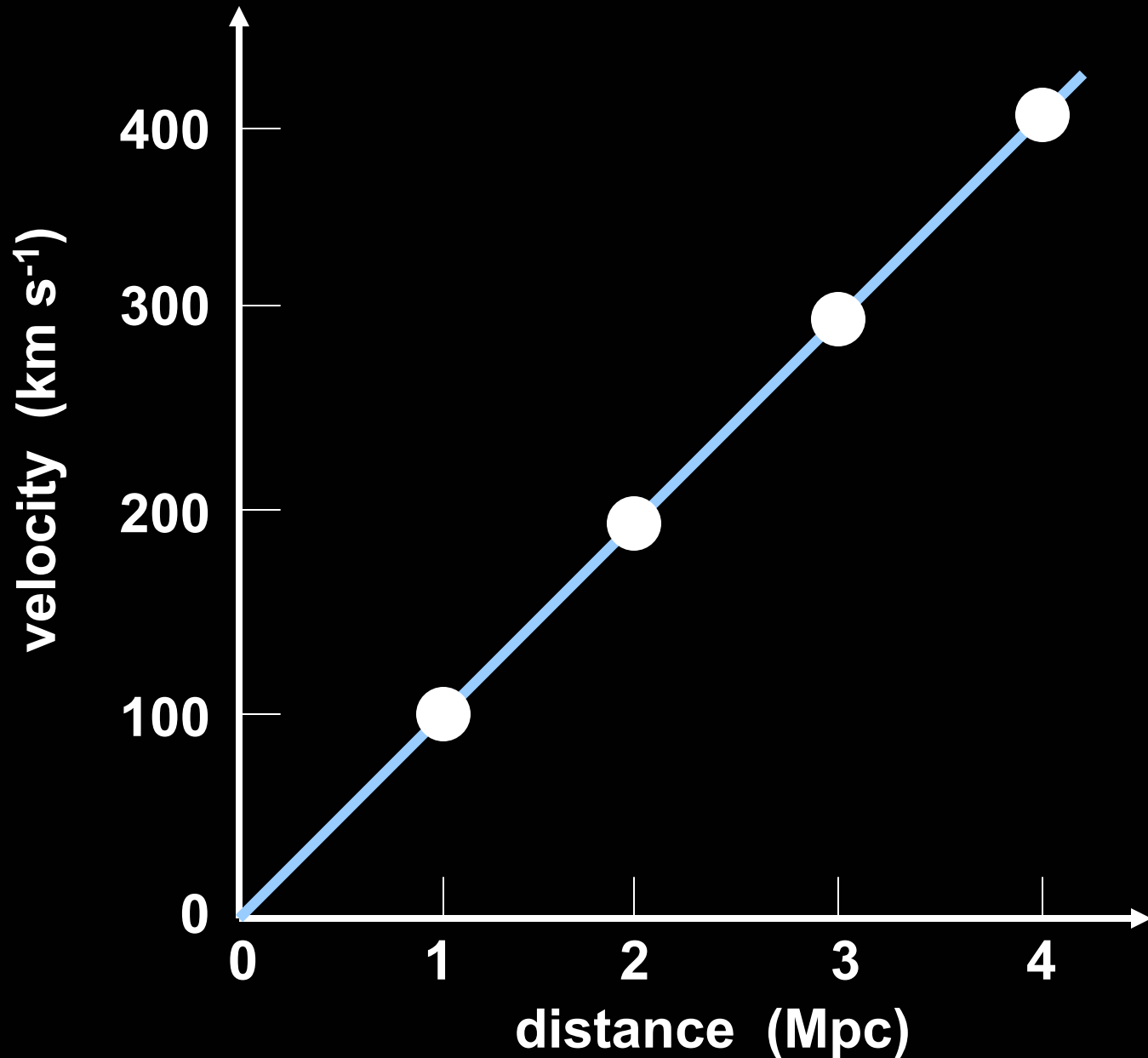
# Hubble's Discovery Paper - 1929



**Why a blue shift for nearby galaxies?**

Hubble's Law:  $v = H_0 d$

( $H_0 = 100 \text{ km s}^{-1} \text{ Mpc}^{-1}$ )



# The Hubble age of the universe

$$\left. \begin{array}{l} d = vt \quad \text{distance} = \text{velocity} \times \text{time} \\ d = vH_0^{-1} \quad \text{Hubble's law} \end{array} \right\} t = H_0^{-1}$$

$$H_0 = 100h \frac{\cancel{\text{km}}}{\text{s}} \frac{1}{\cancel{\text{Mpc}}} \times \frac{1 \cancel{\text{Mpc}}}{3 \times 10^{19} \cancel{\text{km}}}$$

$$(0.8 \geq h \geq 0.6)$$

$$= \frac{100h}{3 \times 10^{19}} \frac{1}{\cancel{\text{s}}} \times \frac{3 \times 10^7 \cancel{\text{s}}}{1 \text{ year}}$$

$$= \frac{100h}{10^{12} \text{ years}} = \frac{h}{10^{10} \text{ years}}$$

$$t = 10^{10} h^{-1} \text{ years}$$

$$12.5 \leq t \leq 17 \text{ Gyr}$$

$$1 \text{ Gyr} = 10^9 \text{ years}$$

# The age of the elements

- Elements come in different isotopes  
(same # of protons, different number of neutrons)
- Many isotopes are radioactive — they decay
- If start with  $N(0)$  nuclei, after a time  $t$ , the number will be

$$N(t) = N(0) 2^{-t/\tau_{1/2}}$$

$\tau_{1/2}$  is the half-life

Can use radioactive isotopes to date objects  
Radio dating .... nucleocosmochronology

# **$^{14}\text{C}$ dating**

- Carbon has two main isotopes  $^{12}\text{C}$  and  $^{14}\text{C}$
- $^{14}\text{C}$  (6 protons + 8 neutrons) is unstable
  - half life of 5,746 years
- $^{12}\text{C}$  (6 protons + 6 neutrons) is stable
  - it doesn't decay

$$N_{14}(t) = N_{14}(0) 2^{-t/5746 \text{ years}}$$

$$N_{12}(t) = N_{12}(0)$$

$$\frac{N_{14}}{N_{12}}(t) = \frac{N_{14}}{N_{12}}(0) 2^{-t/5746 \text{ years}}$$

# *Torino*



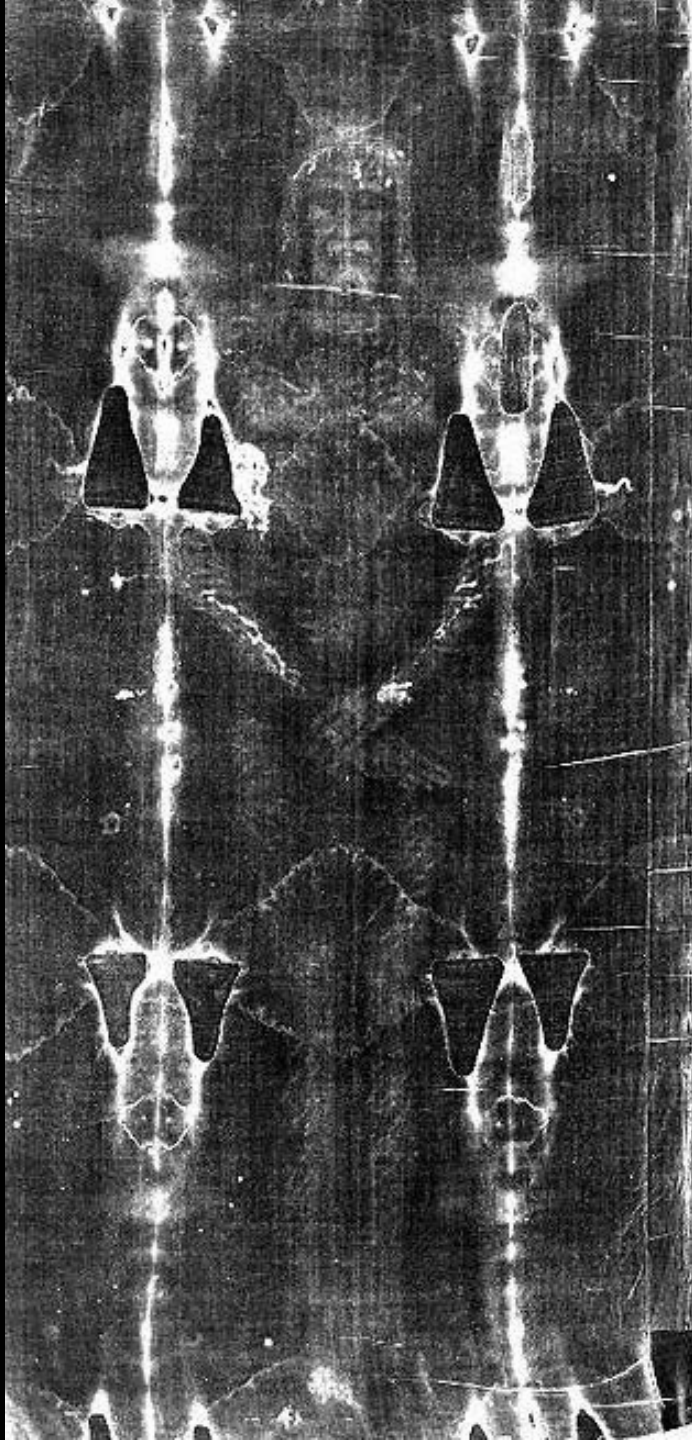
**il Duomo di Torino (1498)  
la Cappella della Santa Sindone  
e sullo sfondo la Mole Antonellian**

**Turin Cathedral,  
Holy Shroud Chapel  
and Mole Antonelliana**

Thu May 13 16:06:15 2004



© Città di Torino



# The Shroud of Turin



Bill Acosta  
LAS VEGAS IMPRINTS  
Flamingo  
May 1st  
10:00 PM  
flamingo.com

FLAMINGO PALACE

10

TO Fabulous  
LAS VEGAS  
NEVADA

GLASS 2001

# *Caesar's Palace*



# The Shroud of Vegas



# The Shroud of Vegas—25 years old?

- Peanut butter contains  $^{12}\text{C}$  and  $^{14}\text{C}$
- $^{12}\text{C}$  is stable and  $^{14}\text{C}$  is unstable - half-life of 5,746 years

$$\frac{N_{14}}{N_{12}}(t) = \frac{N_{14}}{N_{12}}(0) 2^{-25 \text{ years} / 5746 \text{ years}}$$
$$= \frac{N_{14}}{N_{12}}(0) 2^{-0.004} = 0.997$$

# The Shroud of Vegas—25 years old?

- B-B-Q sauce contains  $^{23}\text{Na}$  and  $^{20}\text{Na}$
- $^{23}\text{Na}$  is stable and  $^{20}\text{Na}$  is unstable - half-life of 0.4 seconds

$$\frac{N_{20}}{N_{23}}(t) = \frac{N_{20}}{N_{23}}(0) 2^{-25 \text{ years} / 0.4 \text{ seconds}}$$

$$= \frac{N_{20}}{N_{23}}(0) 2^{-1,811,250,000} \approx 0$$

# The Shroud of Vegas—25 years old?

- Hair mousse contains  $^1\text{H}$  and  $^3\text{H}$
- $^1\text{H}$  is stable and  $^3\text{H}$  is unstable - half-life of 12.5 years

$$\frac{N_3}{N_1}(t) = \frac{N_3}{N_1}(0) 2^{-25 \text{ years}/12.5 \text{ years}}$$

$$= \frac{N_3}{N_1}(0) 2^{-2} = \frac{N_3}{N_1}(0) \times \frac{1}{4}$$

**Moral: use an isotope with appropriate half-life**

**Appropriate: half-life approximately  
the age of the sample**

$$\tau_{1/2}({}^{238}\text{U}) = 4.5 \text{ Gyr}$$

$$\tau_{1/2}({}^{187}\text{Re}) = 40 \text{ Gyr}$$

$$\tau_{1/2}({}^{232}\text{Th}) = 14 \text{ Gyr}$$

**Age of the elements 10 – 18 Gyr**

$$t = 10^{10} h^{-1} \text{ years}$$

$$12.5 \leq t \leq 17 \text{ Gyr}$$

$$1 \text{ Gyr} = 10^9 \text{ years}$$

# Hubble's original value:

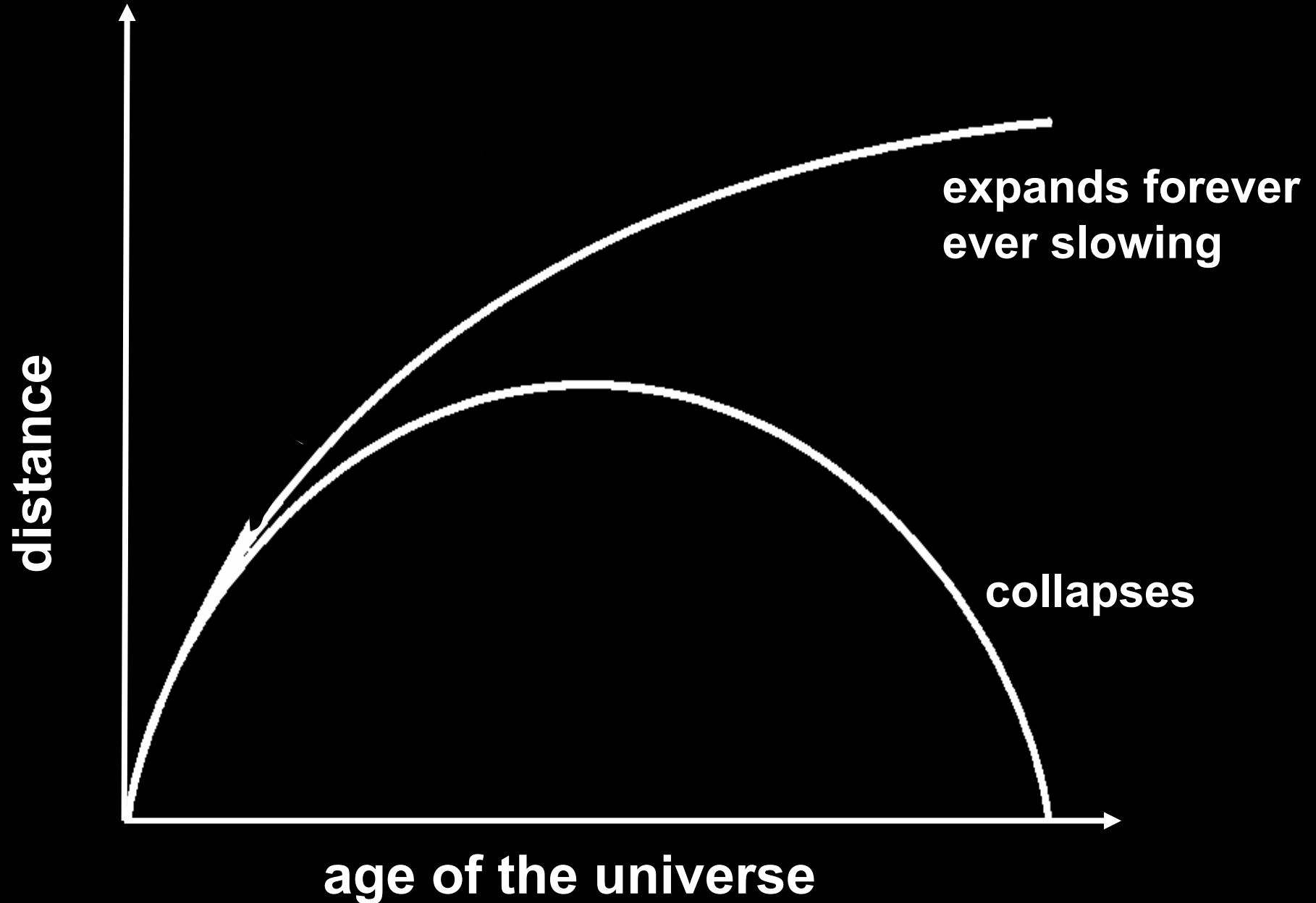
$$H_0 = 500 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

$$h = 5$$

$$t = 10^{10} h^{-1} \text{ years}$$

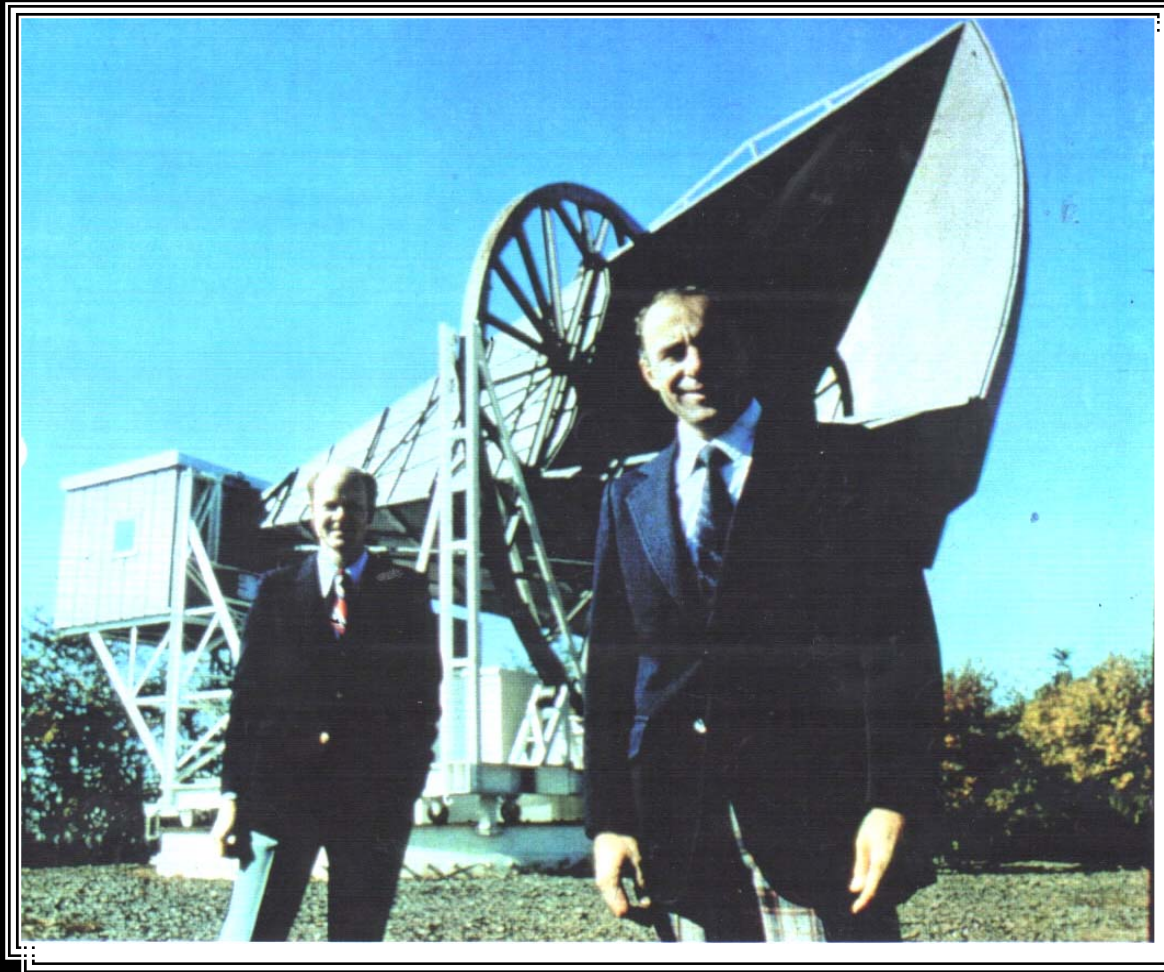
$$t = 2 \text{ Gyr}$$

# ***Evolution of the universe***

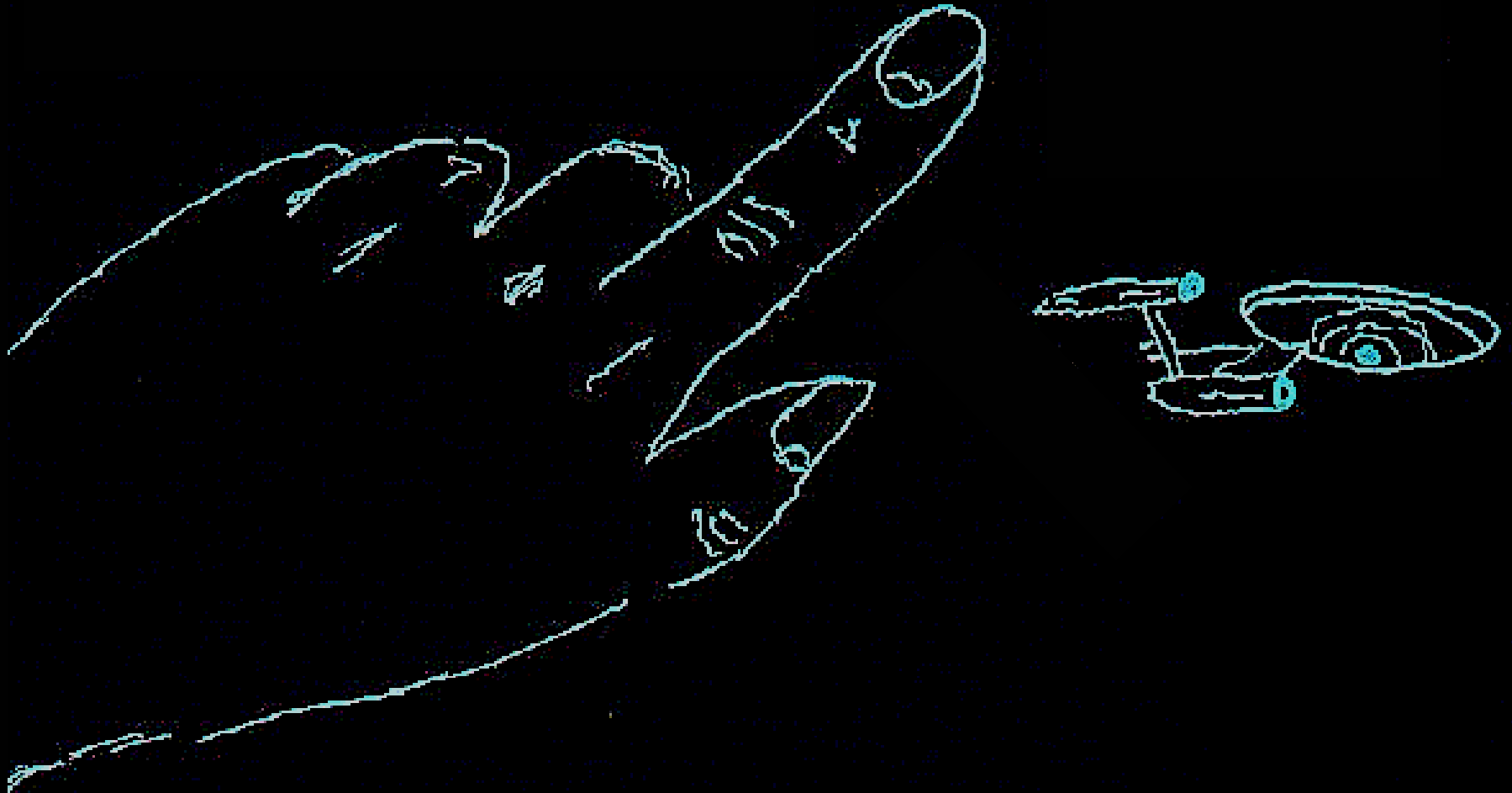


**The universe  
is radiant.**

**Arno Penzias  
Robert Wilson  
1965**

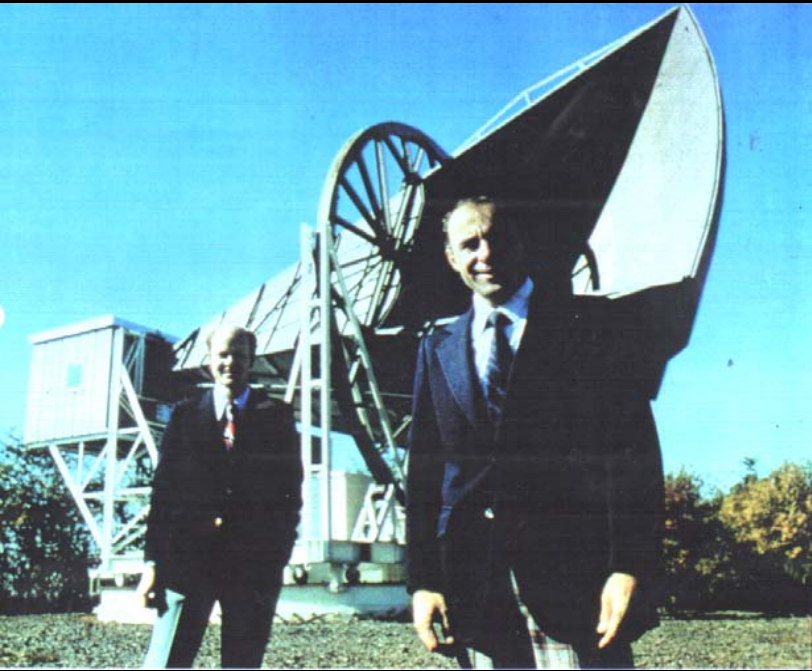


# **Cosmic background radiation**

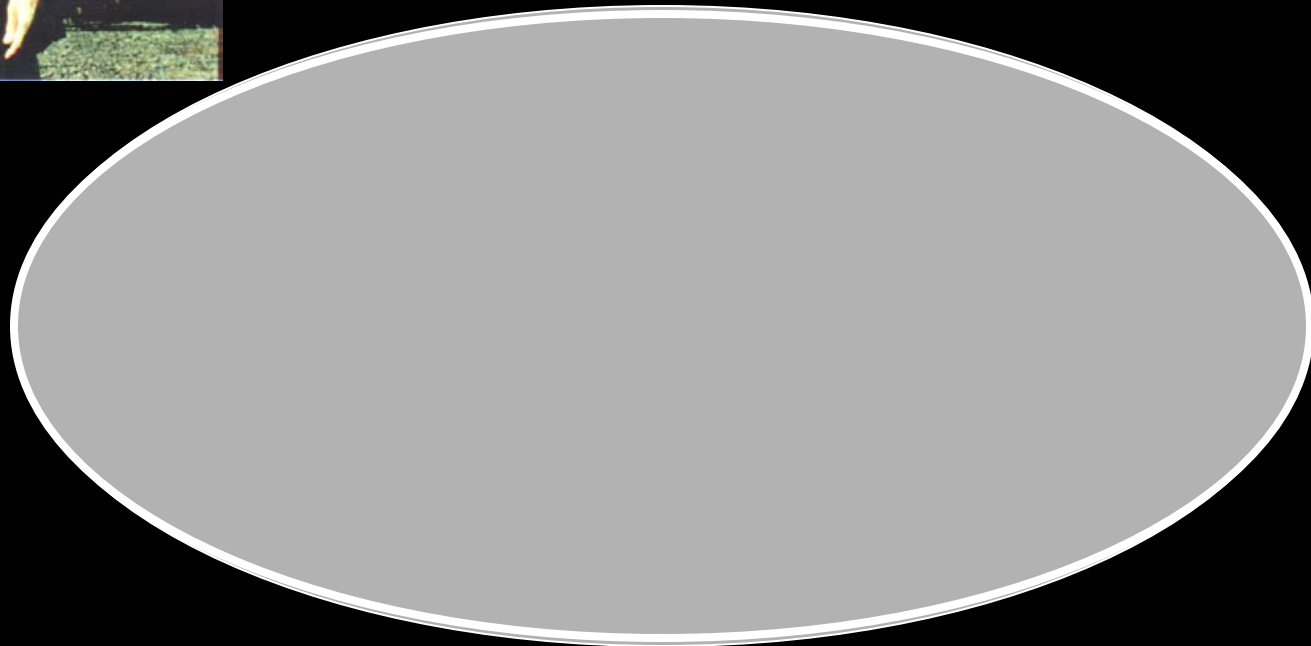


$$T = 3K = -454^{\circ} F$$

# *Cosmic Radiation ca. 1960s*



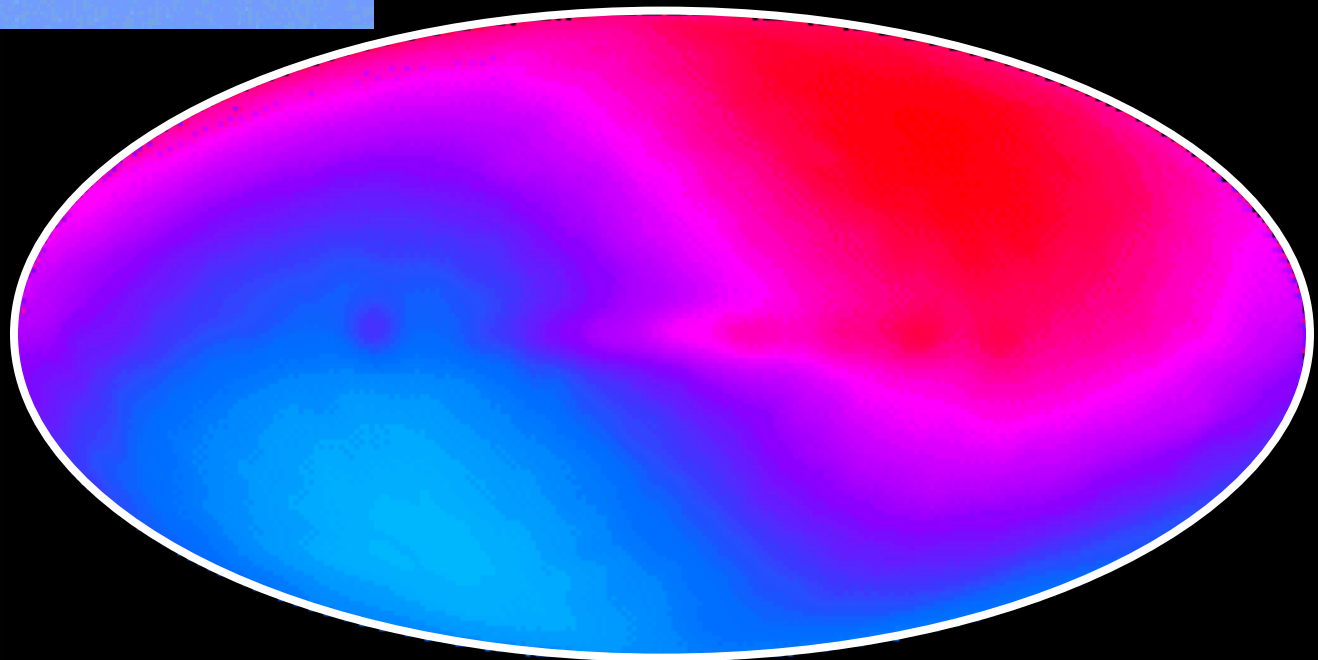
2° 3° 4°



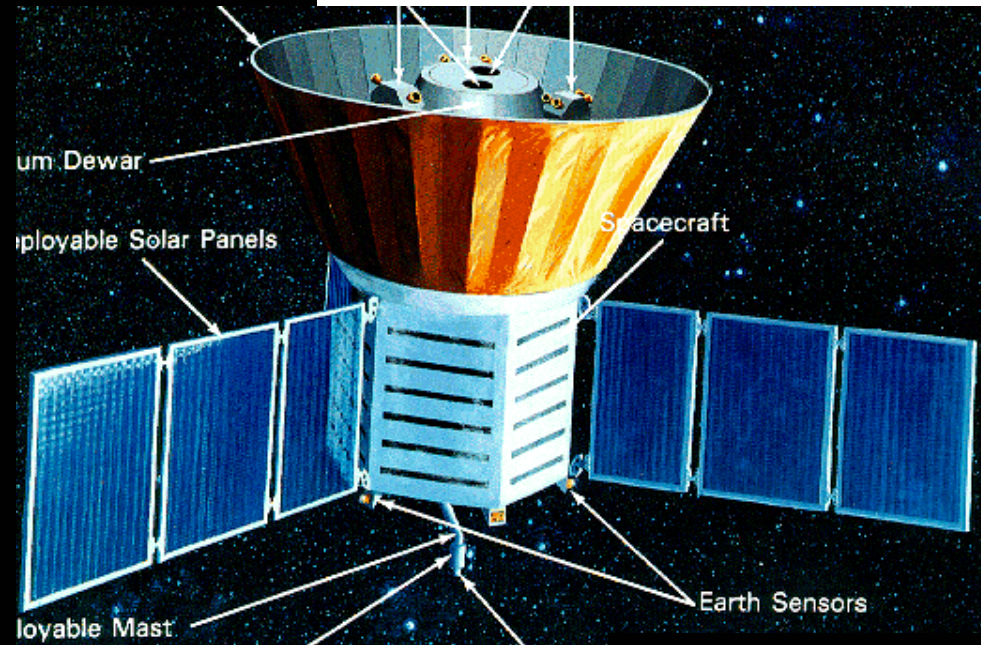
# *Cosmic Radiation ca. 1975*



2.997° 3° 3.003°



# Cosmic Radiation 1992



**COBE**

$2.99997^\circ$   $3^\circ$   $3.00003^\circ$

